

# Cosmology and Dark Energy Group at Argonne

*Steve Kuhlmann*

- Building/Commissioning DECam
- Specialized studies of DECam CCDs
- PreCam (e.g., “mini-DECam”)
- Supernova Cosmology
- Supercomputing (Cosmology and Supernovae)
- DES Cluster Science and the South Pole Telescope



DARK ENERGY  
SURVEY



Office of Science  
U.S. Department of Energy

Growing focus on science

# ***Cosmology and Dark Energy Group at Argonne***

***In FY10 1.2 FTE Staff and 2 post-docs funded from KA-13***

## **Dark Energy Survey group members:**

Joe Bernstein (former DES post-doc, current computational fellow working on supercomputing applications in cosmology and supernova)

Rahul Biswas (new post-doc working on supernova and cosmology)

Kyler Kuehn (post-doc working on PreCam)

Steve Kuhlmann (group leader)

Hal Spinka (staff working on supernova and PreCam/CCDs)

Rich Talaga (staff working on PreCam/CCDs)

## **Additional:**

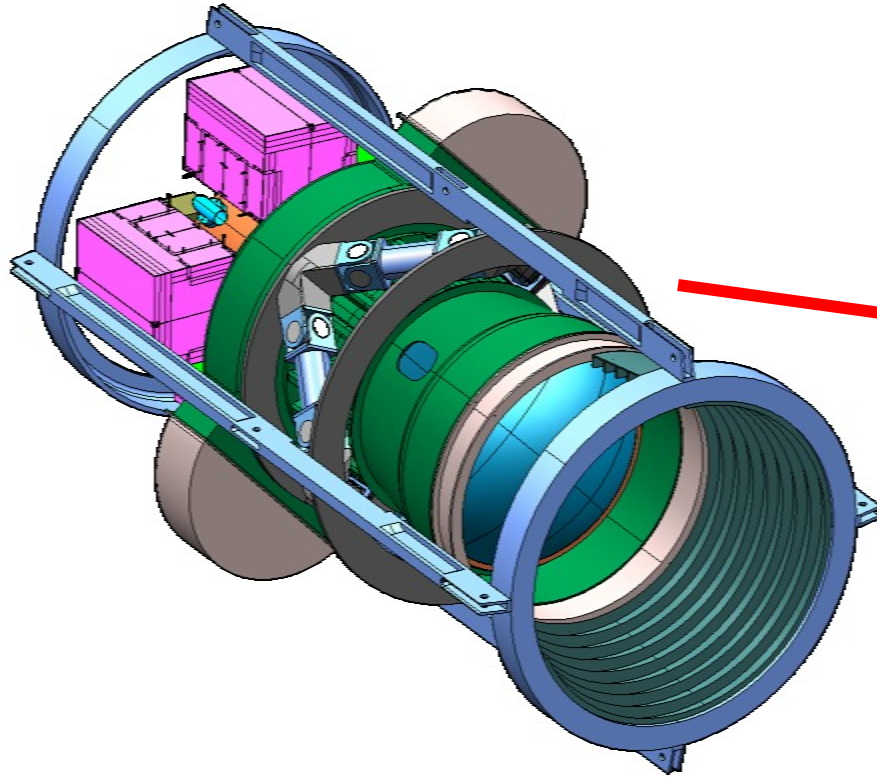
Eve Kovacs (software support + supernova)

John Cunningham + students (Loyola visitor working on supernova)

Ian Crane (UIUC student working on supernova)

Dallas Turner (Rockford High Schools, supernova outreach)

## *Dark Energy Camera (DECam), ANL mechanical effort*

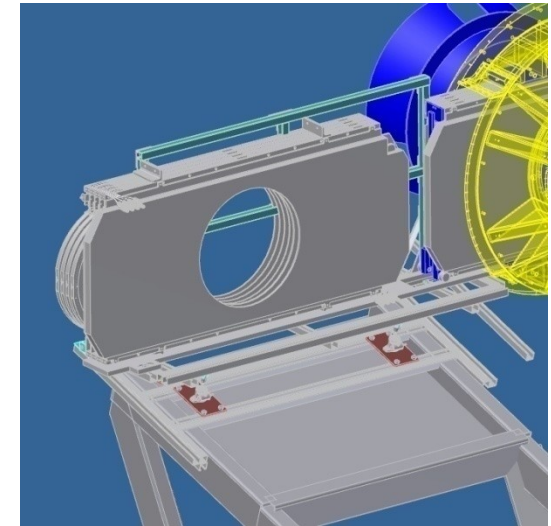


### **Mechanical Engineers and support:**

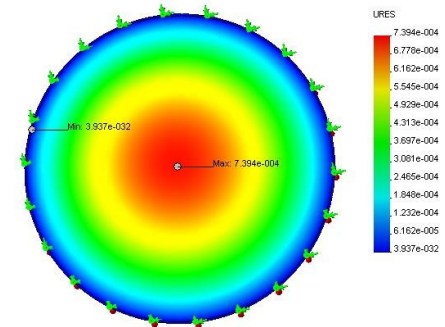
Allen Zhao, Vic Guarino, Tom Kasprzyk,  
Frank Skrzecz, + NE engineering group  
(3 engineers + 2 designers)

# Dark Energy Camera (DECam), many engineering roles for ANL

- **>\$1.3M of DECam project funding for ANL mechanical design, procurement, assembly and testing.**
- **More than 20% of entire DECam mechanical effort, despite being one of last institutions to join.**
- **CCD focal plane thermal analysis**
- **f/8 Secondary Mirror Installation System – ANL L3**
- **Instrument Control System – ANL L3 manager (Shutter control, Filters, CCD Temps, Vacuum, LN2, ...)**
- **Electronics cooling system – ANL L3 manager**
- **Telescope simulator inner rings – ANL L3 manager**
- **Filter changer and shutter installation mechanism – ANL L3**
- **C5 cell and test vessel – ANL L3 manager**



C5-PEA3-Static-Thermal :: Static Displacement  
Units : in Deformation Scale 1 : 2704.93





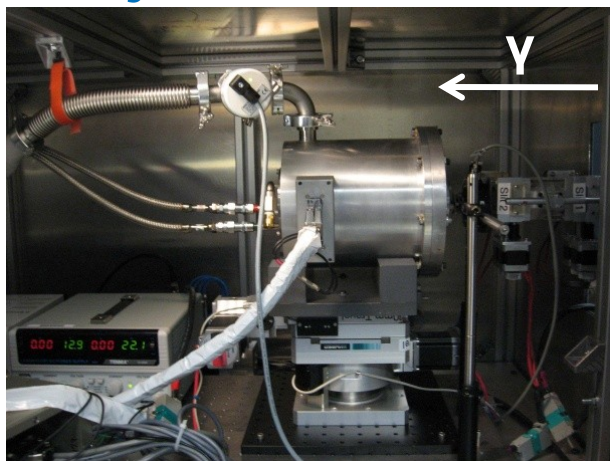
# *f/8 Handling System*

- Used to install and remove the f/8 secondary mirror from DECam
- Lead Engineer Allen Zhao (ANL) led the design, procurement, assembly and testing at ANL.
- FNAL testing complete, CTIO participated in testing and sign-off.
- First piece of DECam to go through acceptance testing
- Shipping to CTIO now.

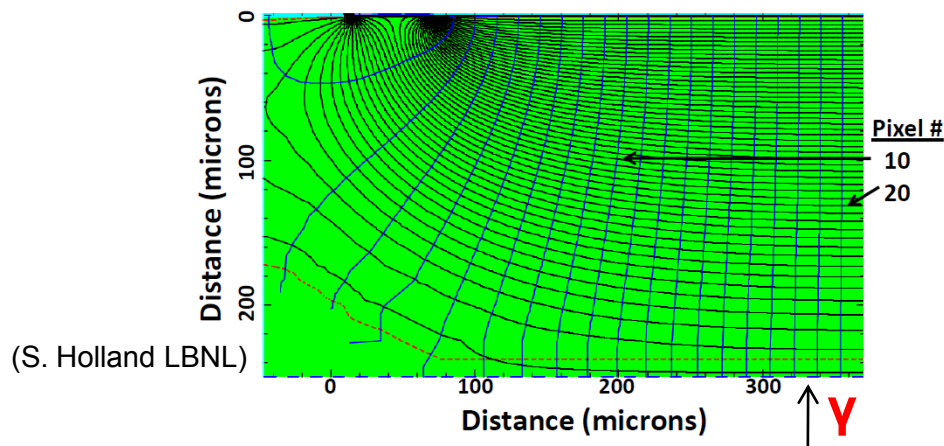
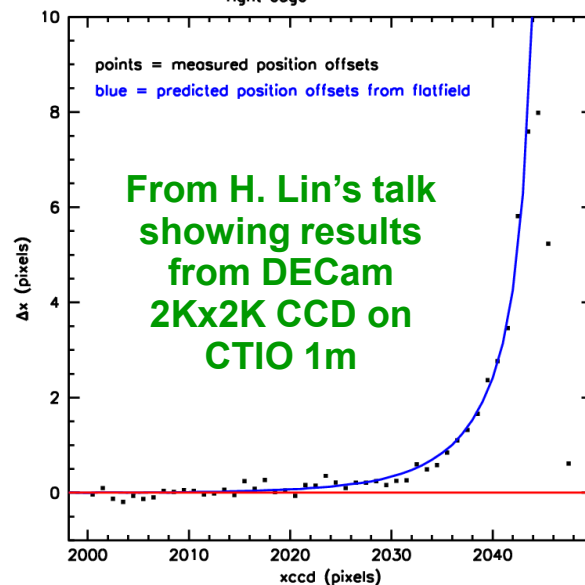


Inner simulator rings  
also engineered at ANL

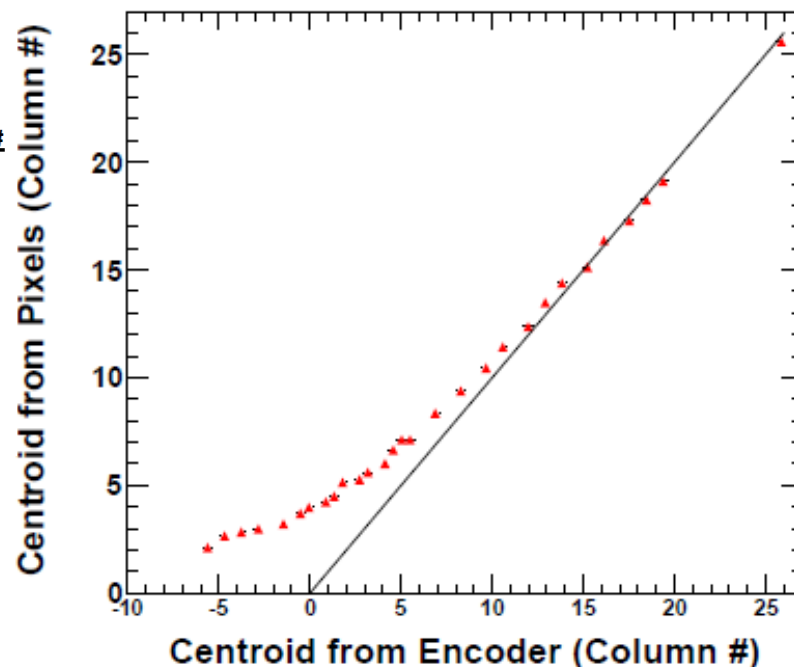
# DECam Charged Coupled Device Studies: X-ray irradiation studies in APS X-ray Lab



**Paper resubmitted  
with additional plots**



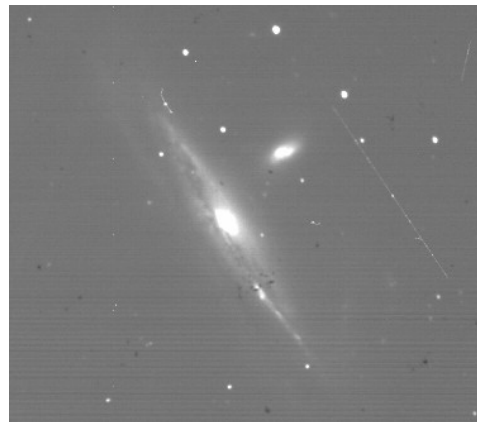
**Sub-pixel scanning  
capability, possible future  
DECam tests.**



## **PreCam: a “mini-DECam,” camera developed/built at ANL**

- Science motivation for pre-survey observations with DECam hardware
  - 0.01 calibrated stars/image w/o PreCam, ~1000/image with PreCam
  - reach 2% photometry requirement faster, and better chance at 1% goal
  - possible 10% savings (~\$1M!) in telescope time
  - Relative calibrations between surveys is a crucial SN DE uncertainty
- Test-bed for DECam hardware, software, and observing strategies
- PreCam engineering run just finished at CTIO, **first light Aug 30<sup>th</sup>**

**Interacting  
galaxies  
NGC1531 and  
NGC1532**



**Globular  
cluster 47 Tuc**





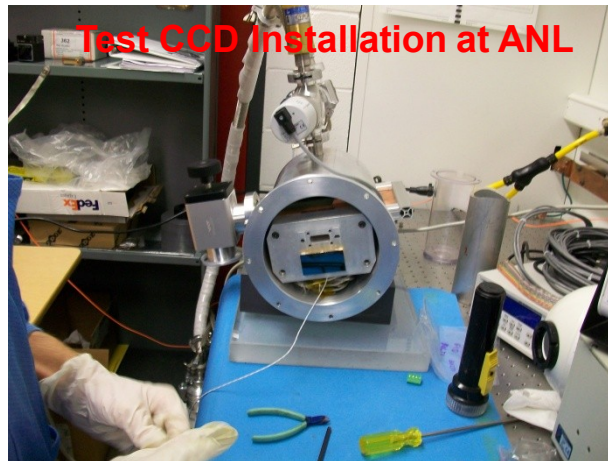
# PreCam Camera Development



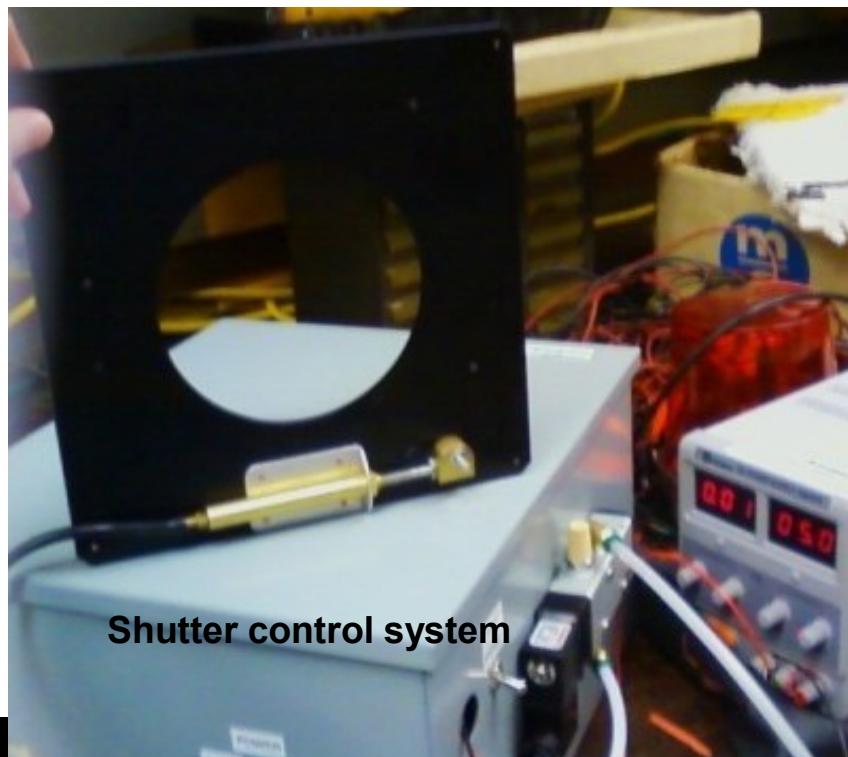
Test CCD Installation at ANL



Test CCD Installation at ANL

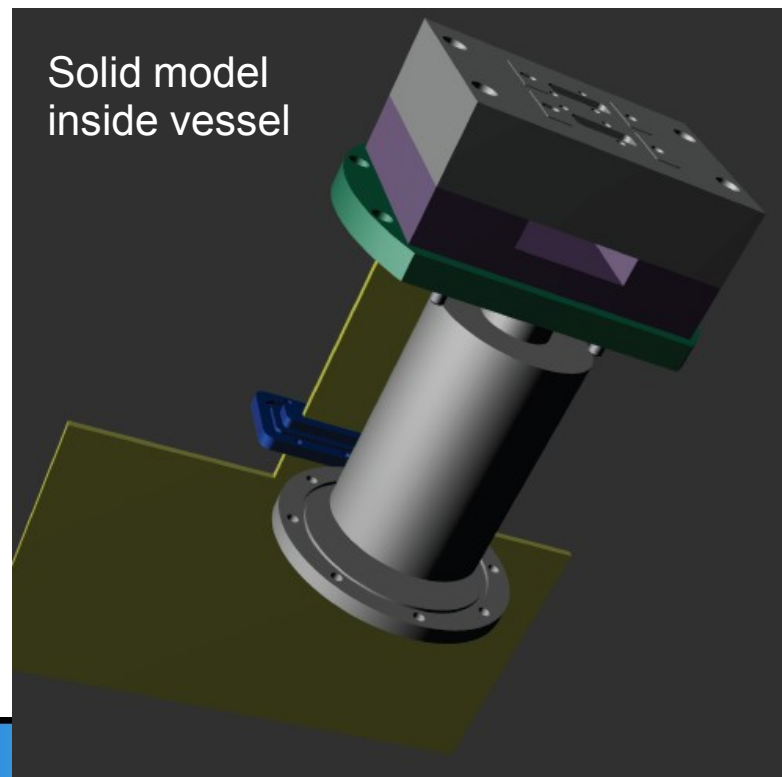


Real CCD Installation at FNAL



Shutter control system

Solid model  
inside vessel





# PreCam Commissioning

**Camera worked with minimal downtime (<5%) over one month of observations. Several small problems that did not affect optics tests.**

**Optics issues of a parallel telescope upgrade (non-ANL) dominated the engineering run, resolved last weekend. Good alignment and focus over focal plane.**

**Many useful DECam system tests.**



**First of two PreCam shipments arriving in Chile.**



**Kyler Kuehn (ANL) and Jorge Briones (CTIO) during Aug 30<sup>th</sup> camera installation.**

## *PreCam as trail-blazer for DECam*



CCD shipping test. Engineering CCDs inside vessel and science-grade CCDs shipped independently arrived in great condition.

DECam clean room at CTIO not ready for PreCam arrival, push to finish this week.

Data transfer to Brazil portal and Fermilab very slow at beginning, now is routine.

DAQ software working reliably despite many upgrades during commissioning.

*First calibration/science run Nov 16-Jan 29*

# Supernova Cosmology at ANL: Overview

- Leading DES strategy/systematics paper, Bernstein first author.
- One of only three groups that are members of SDSS/DES/LSST supernova collaborations. Hosting SDSS SN collab meeting in Oct.
- Dedicated post-doc working on joint full-sample SDSS-SNLS analysis and retraining SALT light curve fitter. SDSS photo-z and host galaxy correlation authorship. Important for DES/LSST.
- Leading LSST SN statistics and cosmology constraints in ScienceBook.
- Core developer of SNANA empirical analysis/simulation package, including core collapse simulations.
- Pushing the connections between supercomputer explosion+radiative-transfer models and data comparisons. Long-term project to improve data understanding for precision cosmology.



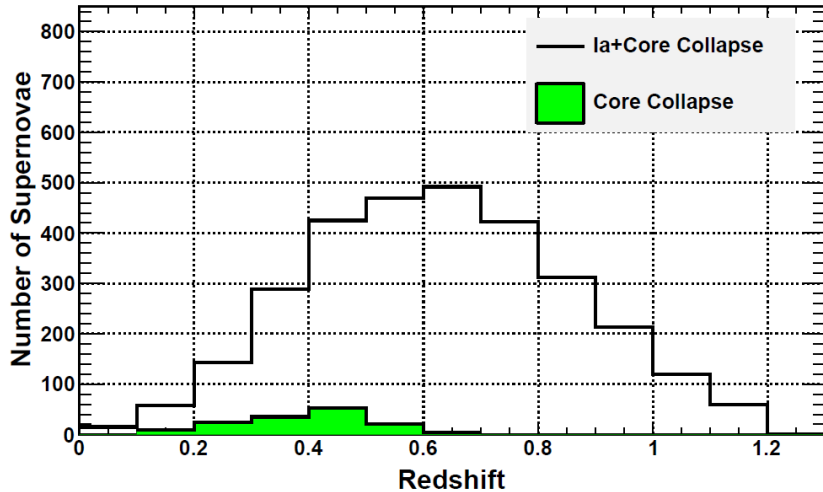
# ***Precision Supernova Cosmology: Challenges***

- Dust effects and color fluctuations
- Relative Calibrations between low- $z$  and high- $z$
- Core collapse SN faking Ia
- Evolution with redshift including galaxy correlations
- Light-curve fitting differences ( $w$  0.25 different in Kessler09)
- Uncertainty in the UV end of the SN spectrum
- Lack of detailed understanding of the explosion and correlations with brightness and fluctuations

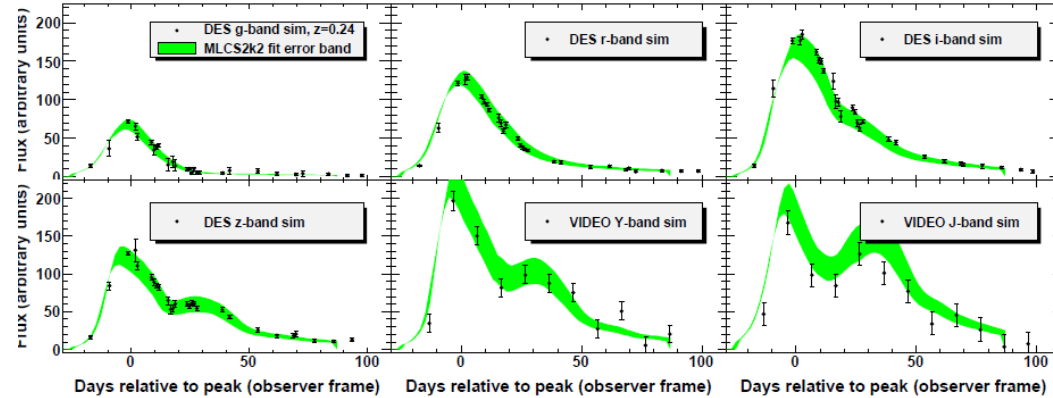
**Next few slides describe how ANL is addressing these...**

# Important aspects of the DES Supernova Survey

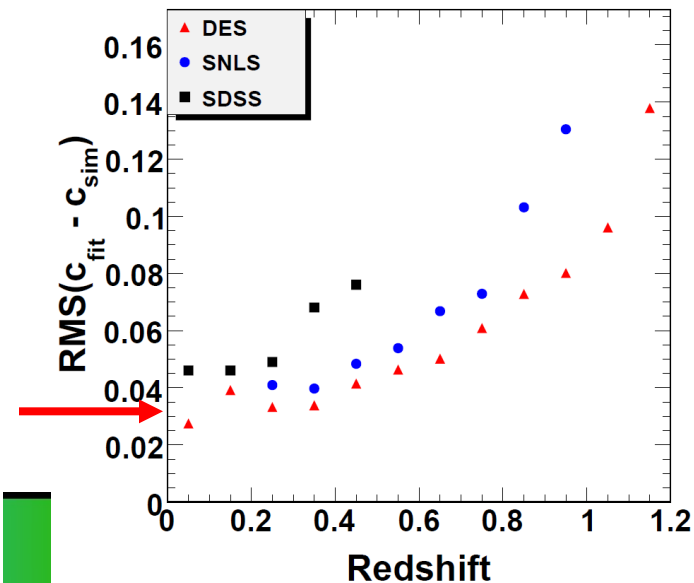
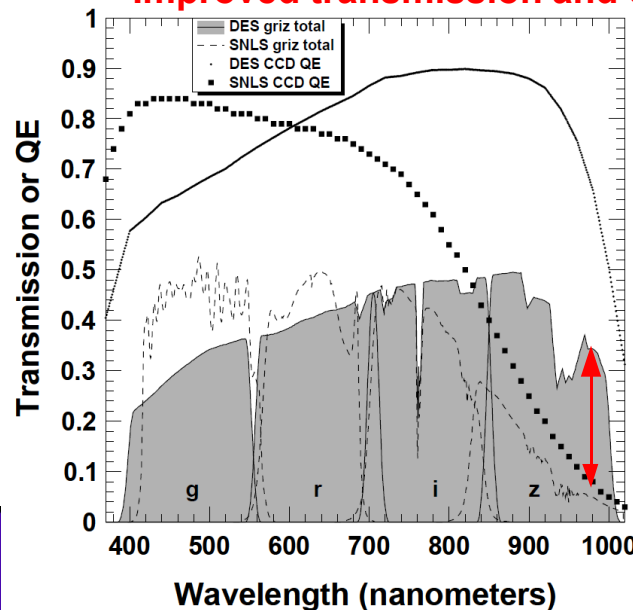
## Deep survey (compared to Pan-STARRS)



## Complementary Infrared information from VIDEO



## Improved transmission and colors relative to SNLS & SDSS



Supernovae Simulations and Strategies:  
Application to the Dark Energy Survey  
(Draft: April 19, 2010)

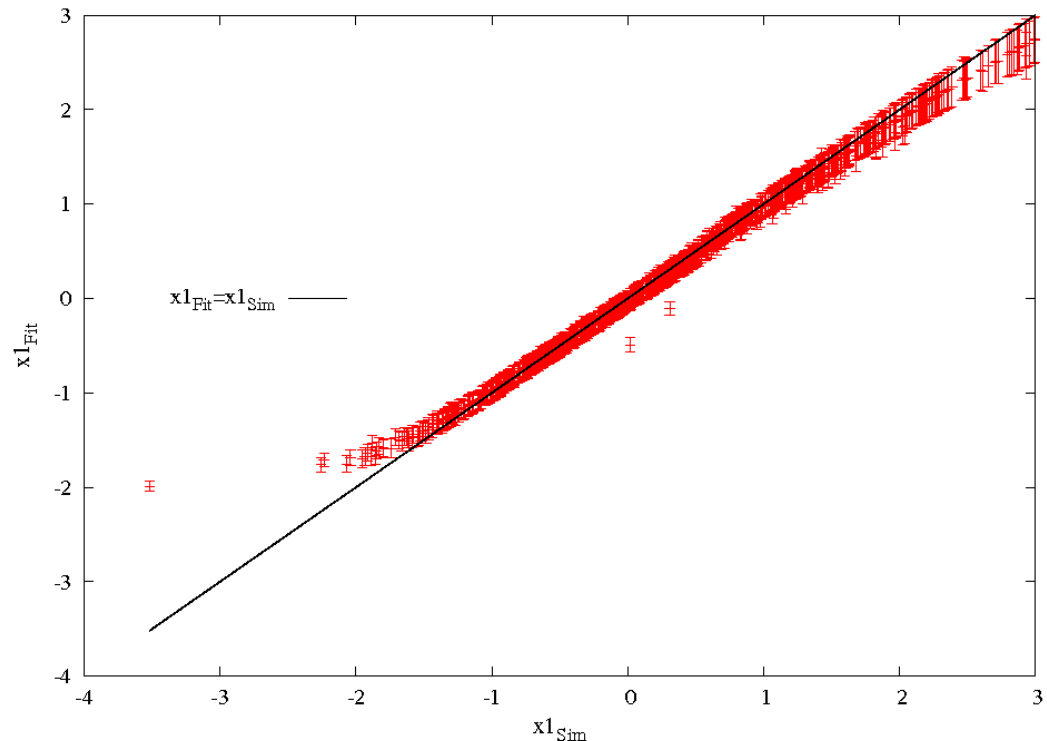
J. P. Bernstein<sup>1</sup>, R. Kessler<sup>2,3</sup>, S. Kuhlmann<sup>1</sup>, R. Reis<sup>4</sup>,  
I. Crane<sup>1,5</sup>, D. A. Finley<sup>4</sup>, J. A. Frieman<sup>2,3,4</sup>, T. Hufford<sup>1</sup>, A. G. Kim<sup>6</sup>, J. Marriner<sup>4</sup>,  
P. Mukherjee<sup>7</sup>, R. C. Nichol<sup>8</sup>, P. Nugent<sup>6</sup>, D. R. Parkinson<sup>7</sup>, M. Sako<sup>9</sup>, H. Spinka<sup>1</sup>, ...

# Critical Role in full-sample SDSS-SNLS analysis & SALT retraining

ANL post-doc Rahul Biswas

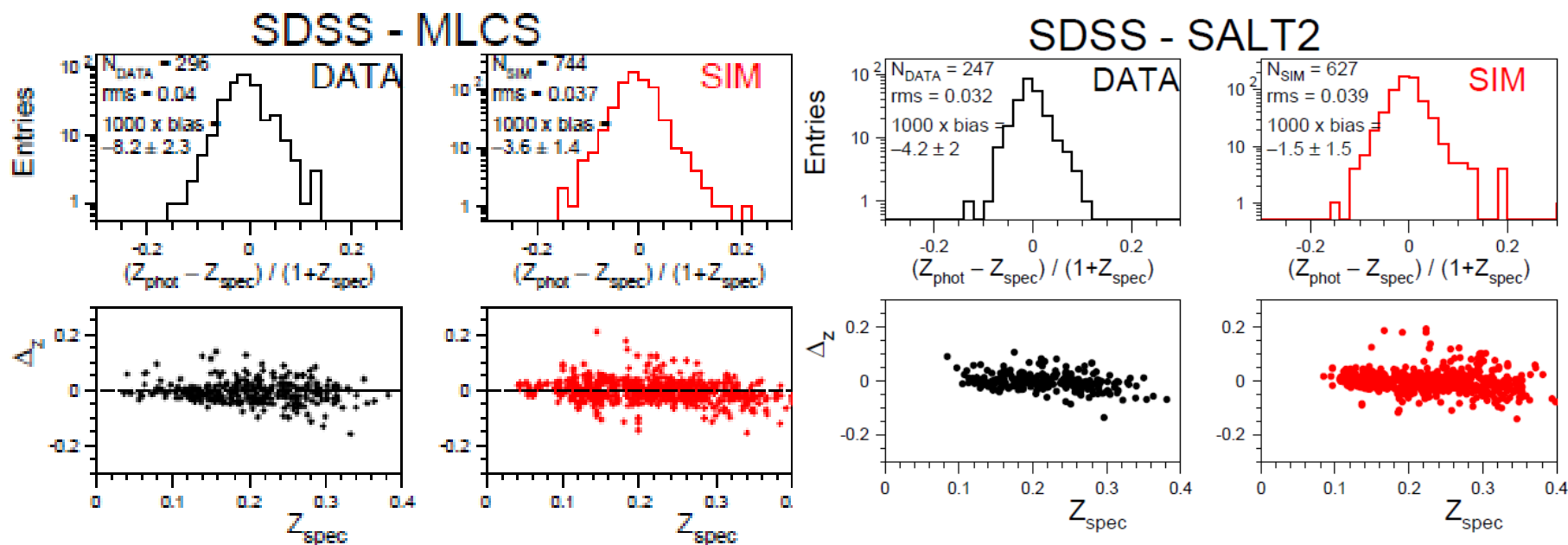
## Code and Training Spectra Test

- Fluctuate Hsiao spectrum and simulate SN
- Train SALT parameters with Kasen spectra
- Fit the simulated data with new SALT parameters
- Compare fitted stretch parameter ( $x1$ ) with simulated





# Photometric Redshift Algorithms and Simulations with SDSS data



## PHOTOMETRIC ESTIMATES OF REDSHIFTS AND DISTANCE MODULI FOR TYPE IA SUPERNOVAE

RICHARD KESSLER,<sup>1,2</sup> DAVID CINABRO,<sup>3</sup> BRUCE BASSETT,<sup>11,12</sup> BENJAMIN DILDAY,<sup>4</sup> JOSHUA A. FRIEMAN,<sup>1,2,5</sup>  
 PETER M. GARNAVICH,<sup>6</sup> SAURABH JHA,<sup>4</sup> JOHN MARRINER,<sup>5</sup> ROBERT C. NICHOL,<sup>7</sup> MASAO SAKO,<sup>9</sup> MATHEW SMITH,<sup>11</sup>  
 JOSEPH P. BERNSTEIN,<sup>8</sup> DMITRY BIZYAEV,<sup>13</sup> ARIEL GOOBAR,<sup>14,15</sup> STEPHEN KUHLMANN,<sup>8</sup> DONALD P. SCHNEIDER,<sup>10</sup>  
 MAXIMILIAN STRITZINGER<sup>16,17</sup>

*Accepted by ApJ*

# Supernova Photometric Classification Challenge

Blind sample of simulated Type-Ia and Core Collapse SN, 10 groups participate

| Name(s)   | abbreviation <sup>a</sup> | classified<br>+Z <sup>b</sup> /noZ <sup>e</sup> | SN<br>z <sub>ph</sub> <sup>d</sup> | CPU <sup>e</sup> | description  |
|---|---------------------------|---|------------------------------------|------------------|--|
| P. Belov & S. Glazov  | Belov+Glazov              | yes/no  | no                                 | 90               | light curve $\chi^2$ test against Nugent templates                 |
| S. Gonzalez   | Gonzalez                  | yes/yes   | no                                 | 120              | SiFTO $\chi^2$ with floated redshift                               |
| J. Richards, D. Homrighausen,<br>C. Schafer, P. Freeman                                 | INCA <sup>f</sup>         | no/yes  | no                                 | 1                | spline fit & nonlinear dimensionality reduction                    |
| J. Newling, M. Varuguese,   | JEDI KDE                  | yes/yes   | no                                 | 10               | Kernel Density Evaluation with 21 params                           |
| B. Bassett, R. Hlozek,  | JEDI Boost                | yes/yes   | no                                 | 10               | Boosted decision trees   |
| D. Parkinson, M. Smith,   | JEDI Hub                  | yes/no  | no                                 | 10               | Hubble diagram KDE   |
| H. Campbell, M. Hilton,<br>H. Lampeitl, M. Kunz,<br>P. Patel (JEDI group <sup>g</sup> ) | JEDI Combo                | yes/no  | no                                 | 10               | Boosted decision trees + Hubble KDE                                |
| S. Philip, V. Bhatnagar,  | MGU+DU-1 <sup>h</sup>     | no/yes  | no                                 | < 1              | light curve slopes & Difference Boosting Neural Network            |
| A. Singhai, A. Rai,<br>A. Mahabel, K. Indulekha   | MGU+DU-2                  | no/yes  | no                                 | 30               | light curve slopes & Random Forests                                |
| H. Campbell, B. Nichol,   | Portsmouth $\chi^2$       | yes/no  | no                                 | 1                | SALT2- $\chi^2_r$ & False Discovery Rate Statistic                 |
| H. Lampeitl, M. Smith   | Portsmouth Hub            | yes/no  | no                                 | 1                | Deviation from parametrized Hubble diagram                         |
| D. Poznanski  | Poz2007 RAW               | yes/no  | yes                                | 2                | SN Automated Bayesian Classifier (SN-ABC)                          |
|   | Poz2007 OPT               | yes/no  | yes                                | 2                | SN-ABC with cuts to optimize $C_{FoM-Ia}$ .                        |
| S. Rodney   | Rodney                    | yes/yes   | yes                                | 230              | SN Ontology with Fuzzy Templates                                   |
| M. Sako   | Sako                      | yes/yes   | yes                                | 120              | $\chi^2$ test against grid of templates & Bayesian prob(Ia,Ibc,II) |
| S. Kuhlmann, R. Kessler   | SNANA cuts                | yes/yes   | yes                                | 2                | Cut on SN Ia (MLCS) fit probability, S/N & sampling                |

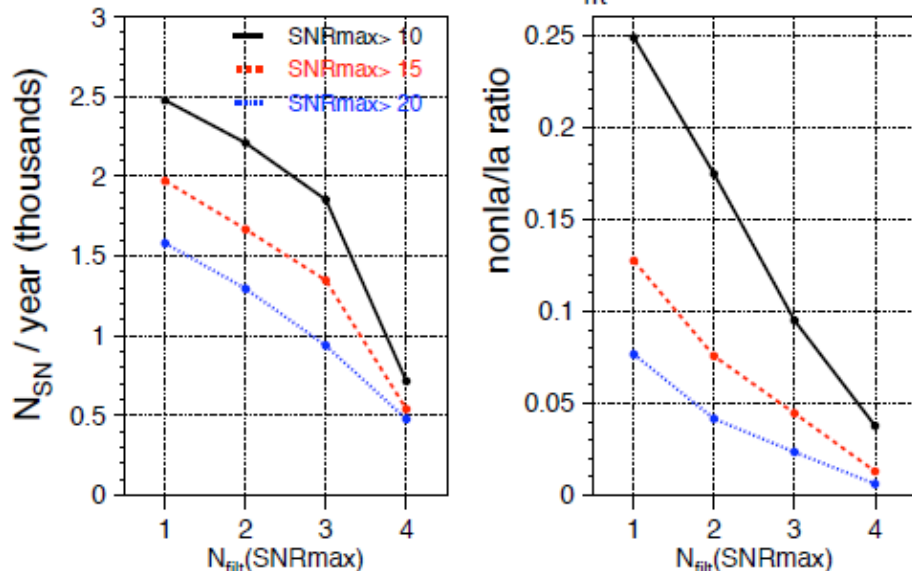
## SUPERNOVA PHOTOMETRIC CLASSIFICATION CHALLENGE

RICHARD KESSLER,<sup>1,2</sup> ALEX CONLEY,<sup>3</sup> SAURABH JHA,<sup>4</sup> STEPHEN KUHLMANN<sup>5</sup>

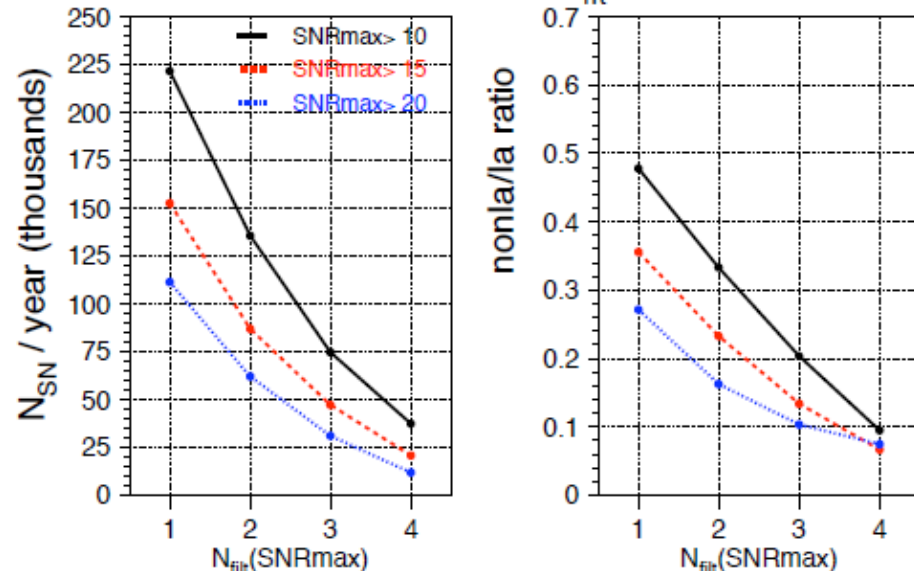
*Challenge Released on Jan 29, 2010. Last update: April 29, 2010*

# LSST Supernova Collaboration, Survey Statistics (ANL simulations)

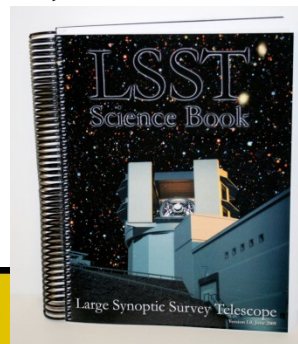
DEEP Survey,  $P_{\text{fit}} > .1$



MAIN Survey,  $P_{\text{fit}} > .1$

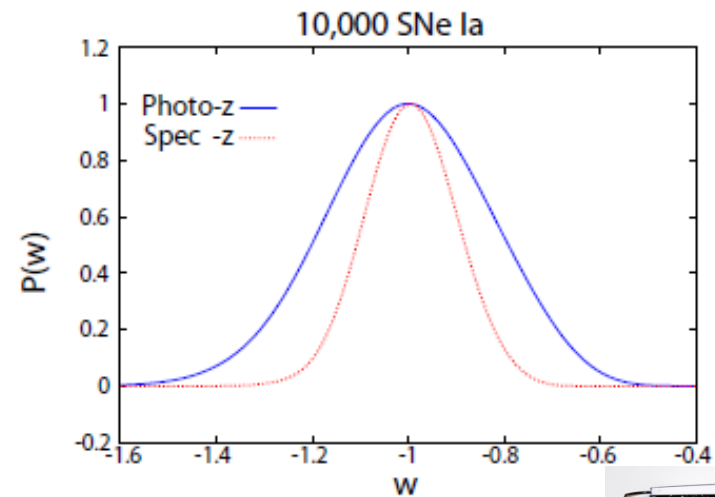
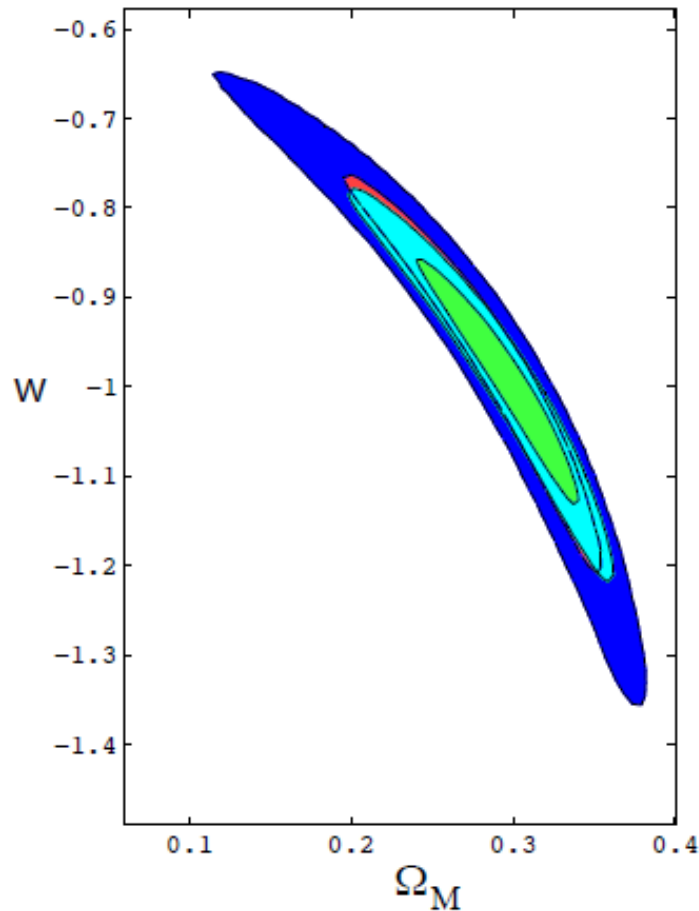


**J.P. Bernstein**, D. Cinabro, R. Kessler, and **S. Kuhlmann**: section 11.3,  
“Simulations of Core-Collapse Supernova Light Curves and Event Rates,”  
*LSST Science Book Version 2.0*.

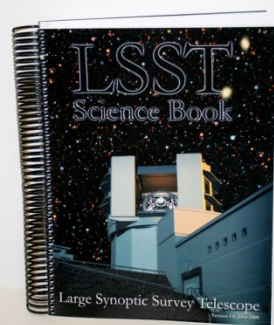




# LSST Supernova Cosmology Results (ANL post-doc Biswas)



P. Pinto, P. Garnavich, W.M. Wood-Vasey, **R. Biswas**, B.D. Wandelt,  
“Constraining the Dark Energy Equation of State,” *LSST Science Book Version 2.0*.



- **Connections to supercomputer modeling groups and resources.**
  - **Detailed comparisons between simulated explosions and data the result of joint ANL/FNAL/UC proposal of which ANL was the lead author and SK co-PI.**
  - **Scaling tests of radiative transfer code using up to 130K processors performed at ANL by Bernstein.**
  - **LDRD proposal to ANL for development of non-local thermal equilibrium software to take the radiative transfer code to the next level.**
- **Asking for Jr. Staff position in mid-FY12 to enhance the supernova cosmology effort when DES data arrives, and Bernstein fellowship ends.**

## *Supercomputing at ANL: Cosmology and Supernovae*

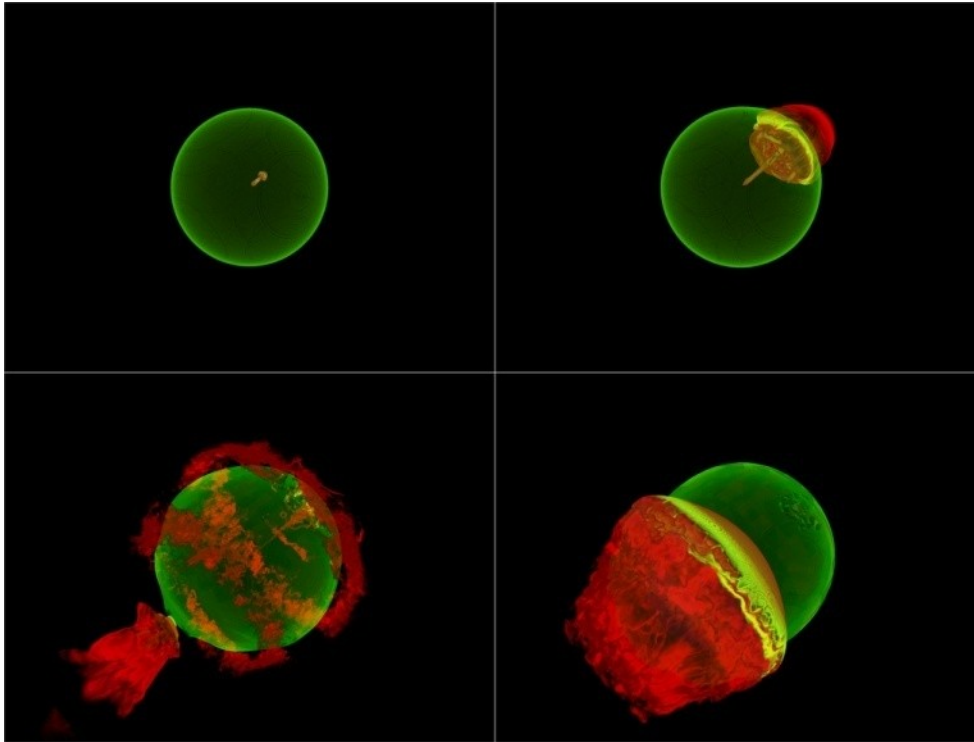
- ANL and Oak Ridge host Leadership Computing Facilities
- Blue Gene/P 164K cores, 0.6 Petaflop, 0.5 GB RAM/core, open science, currently used for FLASH supernova explosion simulations.
- Eureka analysis/visualization 0.1 Petaflop, 200 cores + 200 GPUs, 8 PB disk, 3 TB RAM, open science, used for FLASH SN.
- Fusion 2560 cores, 2432 w/ 36 GB RAM, 128 w/ 96 GB RAM, ANL PI.
- **2012: Blue Gene/Q 750K cores, 10 Petaflop, 1 GB RAM/core, open**
- **BG/Q early science awards: Salman Habib N-Body (ANL post-doc), Don Lamb FLASH Supernovae, ANL/HEP connections with both.**
- **~ 60 computer scientists and software engineers**
- **Offer being prepared for Habib and Katrin Heitmann from LANL, leaders in computational cosmology, to start a ~6 person group funded for three years by ANL. If successful, expect to make major contributions to DES and LSST simulations.**

## Computational Cosmology and Supernovae Simulations

- Using ANL computing resources for cosmology/dark energy/SN, either hardware or people, has always been a priority for our group.
- Previous LDRD with UChicago&FNAL, working with computational scientists on N-Body code.
- **SK co-PI, and J. Bernstein principle author, on successful joint ANL/UC(Lamb)/FNAL(Marriner) proposal to fund a grad student to test SN explosion + radiative transfer simulations with data-driven empirical models such as MLCS/SALT.**
- J. Bernstein moved into ANL Computational Fellowship Feb 15, working on both FLASH SN and computational cosmology.

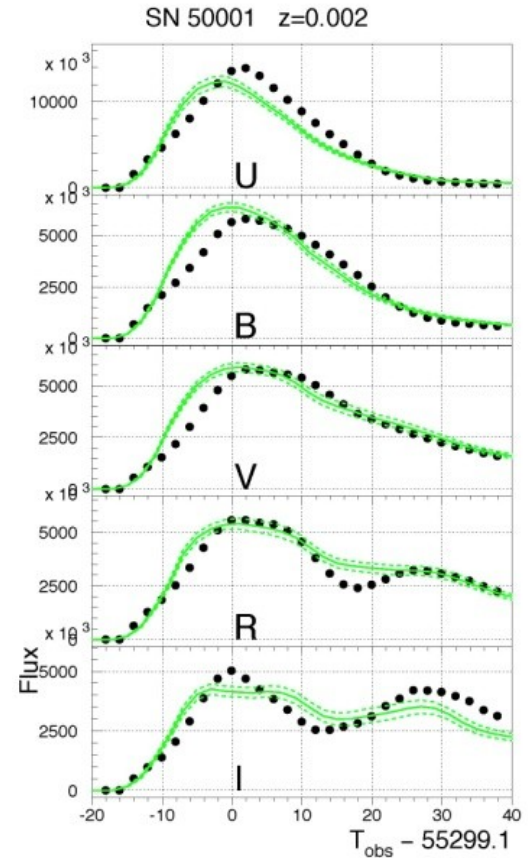


# Supercomputing at ANL: Supernova explosions



Simulated Type Ia explosion  
(gravitationally confined explosion GCD)  
from FLASH/Blue Gene.

Dependence on amount of  $\text{Ni}^{56}$  produced  
and viewing angle important.



Initial comparison of  
simulation (dots) and data-  
driven model (curve)  
(B. Diemer UC student)

## Supernova modeling: Next level in radiative transfer

### Exascale LDRD Proposal, passed first round review.

Proposal Number: 2011-111-N0  
Project Title: Developing Radiative Transfer Models to Elucidate Dark Energy  
Responsible ALD: PSE  
Initiative Area: Exascale Computer Science and Applications  
Lead Investigator: Bernstein, Joseph P. (HEP)  
Co-Investigator(s): Kuhlmann, Stephen E. (HEP); Norris, Boyana R. (MCS);

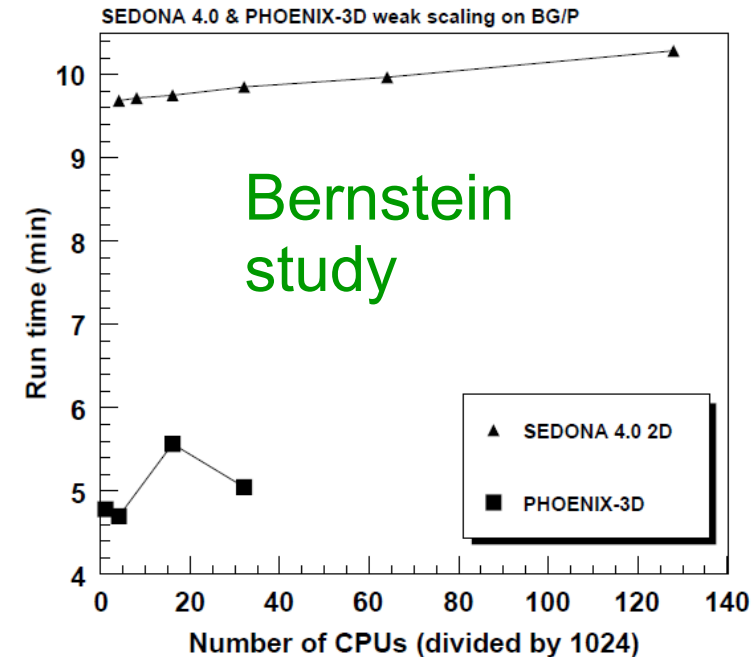


Figure 1: PHOENIX and SEDONA weak scaling on Blue Gene/P.

# Supercomputing at ANL: Cosmology

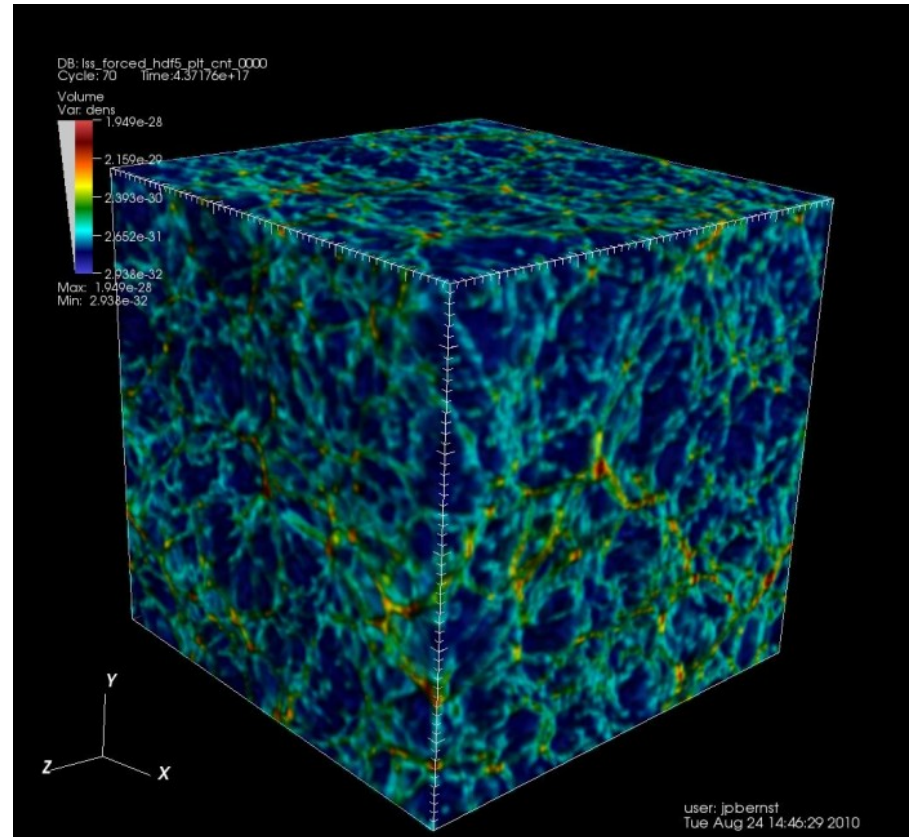
J. Bernstein working with P. Ricker from UIUC on FLASH cosmology module, running on Blue Gene/P.

Scaling tests underway.

Also starting to work with LANL on MC<sup>3</sup> on Blue Gene/P.

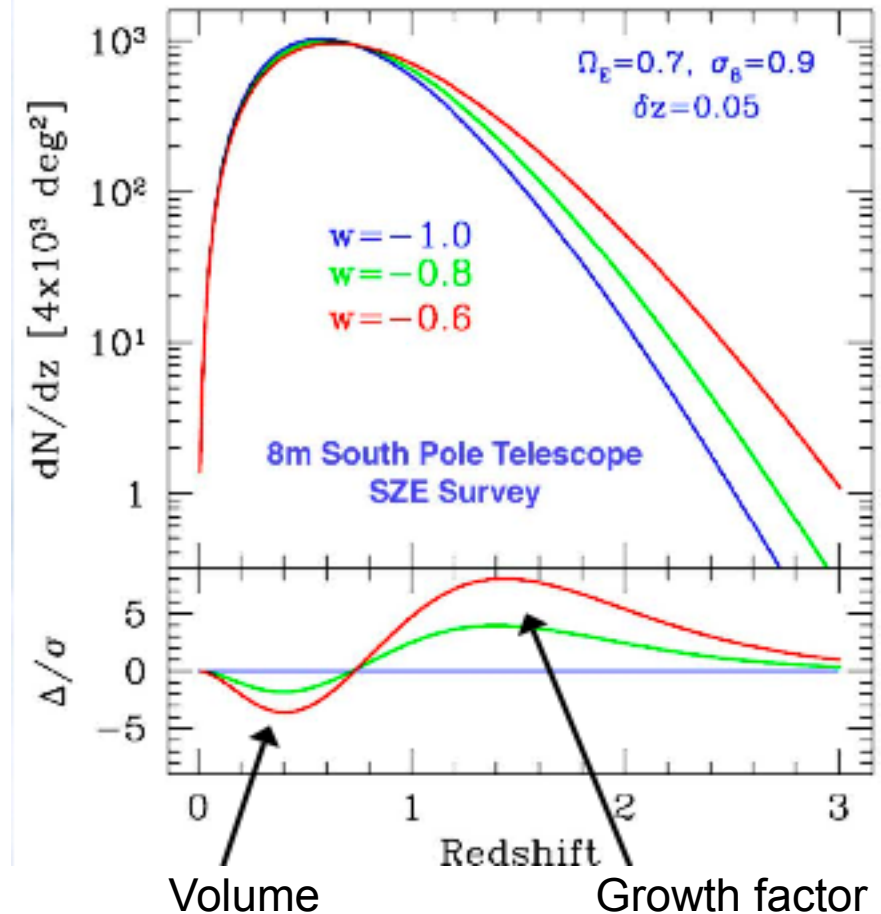
Co-author on exascale computing proposal.

150 million core-hours in early science award on Blue Gene/Q



# DES Galaxy Clusters and the South Pole Telescope

- Important part of DES science and dark energy constraints.
- Will help separate dark energy effects from modified gravity.
- Opportunity for ANL/HEP to collaborate with UC and ANL/MSD on DES science and SPT hardware.





## Conclusions

Important roles in DECam

Leadership role in DES calibrations/PreCam

Large Supernova Cosmology Effort

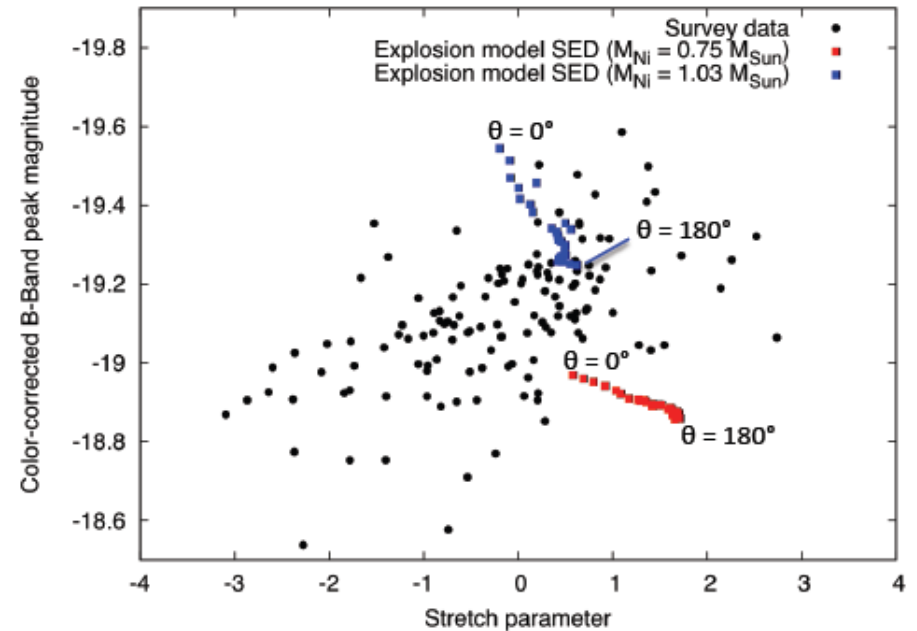
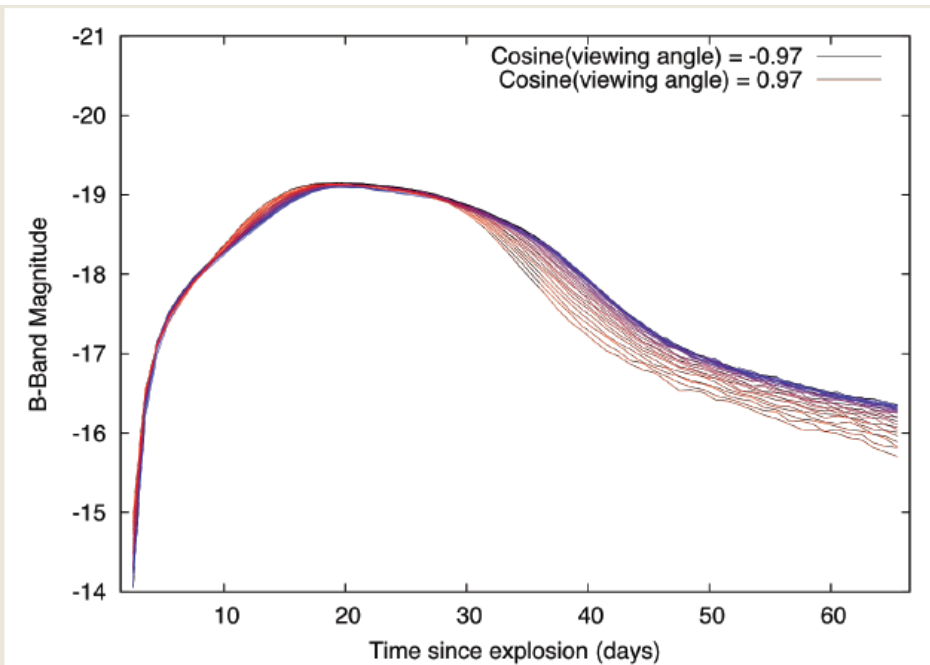
Supercomputing Cosmology and Astrophysics ready to expand

DES Clusters/SPT Excellent Opportunity for ANL/HEP

## *Backup Slides*

# Study of Supernova Explosions versus viewing angle

(B. Diemer)



# *Collaboration with Rockford High Schools on Supernova Studies*

Dallas Turner part of 3-year DOE ACTS program

Telescope/CCD bought last year with DES LDRD

First year goal achieved, see SN from Rockford

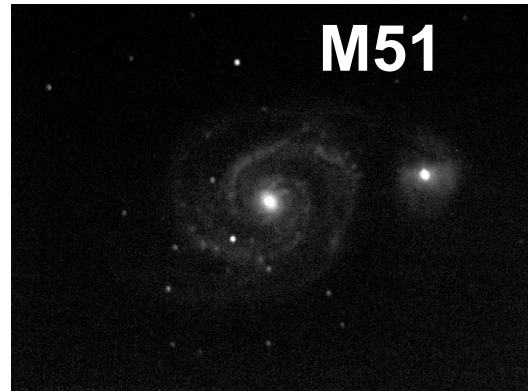
Second year goal, light curves in 3 filters, analysis with DES analysis software



**SN2009ls**



**M51**



**SN2010bj**

